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2. Patent application number *(The Patent Office will fill in this part)*	18 NOV 2003	0326821.6
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	QINETIQ LIMITED Registered Office 85 Buckingham Gate London SW1E 6PD United Kingdom	
08527376002 Patents ADP number *(if you know it)*		
If the applicant is a corporate body, give the country/state of its incorporation	GB	
4. Title of the invention	Flexible Light Sources and Detectors and Applications Thereof	
5. Name of your agent *(if you have one)*	Alastair James TOCHER	
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	QINETIQ LIMITED IP Formalities A4 Bldg Cody Technology Park Ively Road Farnborough Hants GU14 0LX United Kingdom	
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FLEXIBLE LIGHT SOURCES AND DETECTORS AND APPLICATIONS THEREOF

FIELD OF THE INVENTION

The present invention relates to opto-electronic devices in general and in particular to flexible light sources (for example organic light emitting diodes) and detectors, and applications thereof. Applications include, but are not limited to, use in medical applications including therapeutic light sources and patient monitoring equipment.

BACKGROUND TO THE INVENTION

The use of light sources for medical purposes is well known, and may be broadly categorised into use for monitoring purposes and use for therapeutic purposes.

For monitoring purposes it is well-known to use light sources in monitoring devices which take advantage of the absorption spectrum of various blood constituents to facilitate non-intrusive detection of human and animal patient blood characteristics.

One such device is the pulse oximeter, and such devices have been in common use in hospital operating theatres since the 1970's. In more recent years such devices have seen widespread use in other situations, including use in post-operative monitoring, during patient transport, on general wards, and for monitoring of premature or small infants. Neonatal monitoring is an important application of pulse oximetry since premature infants may have periods of apnoea and require extra oxygen. Conversely, it is also important not to oversaturate infants with oxygen. Other medical applications of pulse oximeters include monitoring of aircraft pilots during flight, particularly at altitude where blood oxygen levels may become abnormal, and others operating in environments which may adversely affect blood oxygen levels.

Known pulse oximeters comprise a sensor having a light source and a photodetector. In known oximeters the sensors comprise solid state photodiodes and light emitting diodes (LEDs) to measure light absorption through tissue, typically via a sensor attached to the finger, toe, hand, or foot of the individual to be monitored. Two wavelengths of light – in the red and near infra-red (NIR) spectrum respectively – are emitted in a time-interleaved manner, typically by two adjacent LEDs, with a shared photodiode arranged to detect emissions from each in turn. By measuring the difference in intensity of light received from each LED, a measure of blood oxygen content may be derived by known means.

Some known sensors are manufactured in sizes especially for babies. However even these are far too large for premature and small babies, who need intensive monitoring. These sensors use LEDs which are incorporated into a foam or self-adhesive wrap.

However, referring to Figure 1(a), a known problem with such sensors is that known LEDs 73 are made inside rigid glass or plastic cases which significantly limits the curvature of the sensor device achievable when applying the oximeter to the patient 61. In some cases it is also difficult to achieve good optical contact between the sensor components and the patient's skin owing to the undesirably large size and inflexibility of the sensor components. Since such sensors cannot, for example, closely follow the tight skin curvature of a tiny baby, the sensors are prone to becoming detached or moving with respect to the patient during use and may thereby give rise to false alarms.

A further well-known problem associated with existing oximeters, and similar sensors, is the so-called "penumbra effect". This arises when the respective paths between the multiple light sources and the detector differ significantly. Because known LEDs are discrete rigid devices and effectively provide point sources of light, they cannot typically be sufficiently closely located adjacent one another to ensure that the respective paths to the detector are consistently sufficiently close when the device is actually applied to the patient. Consequently this adds to the difficulties in siting the sensors on a patient and the potential uncertainty of the readings obtained.

Other similar devices are known for monitoring blood characteristics including bilirubin and carbon monoxide (CO) levels. In such devices three or more sources of light at distinct wavelengths are employed so that, in general, two, three, or more are employed according to the characteristic to be monitored.

The rigid nature of the electronic components of existing sensors means that the sensor's carrying strip 71 does not follow well the patients' contours. This problem is partially overcome in known oximeters by the use of self-adhesive strips in which the carrying strip adheres to the patient to avoid rocking and slippage. However, the use of self-adhesive strips has the undesirable side-effect of causing skin irritation in some cases – particularly in young babies – and such strips must therefore be re-sited frequently (for example every 3-4 hours). As a result, the adhesive on the sensor quickly becomes degraded and no longer sticky typically after only a single day's use. Known sensors are sufficiently large as to cover a relatively large area of the patient when in place. This is particularly so in the case of small babies. Because of this, such sensors are often applied over the foot,

even when this site is not otherwise ideal for monitoring the patient, whether medically or for the patient's comfort.

Hook-and-loop fastenings (for example Velcro ™) are well known as a simple and rapid general-purpose fastening and unfastening means. However the lack, in known sensors, of a snug fit around the patient – owing at least in part to the rigid nature of some component parts – means that use of such fastening means alone in known sensors in place of self-adhesion would lead to an arrangement in which the electronic components would be prone to rocking or slipping around the patient. This in turn would give rise to inaccurate readings and ultimately to false alarms were the oximeter to loosen or detach entirely from the patient. If an adhesive strip is, as in known sensors, used in this way there is no need to employ additional attachment means (for example hook-and-loop means) to fasten the strip to itself since attachment to the patient obviates such additional fastening means.

Turning now to therapeutic light sources, it is known to employ phototherapy for skin conditions including, but not limited to, psoriasis. In the case of psoriasis, light in the ultra-violet (UV) spectrum is utilised in treatment. Patients are given a sensitising agent (in tablet or cream form) which acts to sensitise part or all of the patient to UVA radiation (320-400 nm). The patient is then exposed for a time to this wavelength of light by means of a UVA lamp. Exposure is repeated as necessary until treatment is completed. Known light sources are in the form of a conventional UVA lamp located at a moderate distance from the patient and oriented to illuminate the area to be treated. Consequently, some parts of the body may be exposed which do not require specific treatment and, since light from the source is dissipated widely, the available light is also not efficiently directed to the area to be treated.

Unfortunately, and particularly in the case where the patient has taken the sensitising agent in tablet form rather than applying the cream to the affected area to be treated, there is an associated danger of eye damage arising from inadvertent exposure of the eyes to the UVA lamp during treatment. Where the skin condition is widespread, it may nevertheless be more appropriate to introduce the sensitising agent in tablet form and to take physical precautions (for example a UVA-proof blindfold) to protect the eyes.

In photodynamic therapy, patients are injected with special dyes, which then accumulate in tumour sites. The tumour sites are then irradiated with light at a predetermined

wavelength (typically in the red spectrum) which is absorbed by the dyes, resulting in damage to tumour cells where the dye has accumulated.

Organic Light Emitting Diodes (OLEDs) are known in the art and typically comprise a light emitting layer sandwiched between an anode and a cathode. Typically the anode is in contact with a transparent substrate, the anode itself typically being semi-transparent.

Known uses of such OLEDs include thin displays – suitable for computer displays, cellular phones, video cameras, etc. – which may be flexible in nature. Such displays must, by their very nature, comprise a relatively large array of small discrete OLEDs, with potentially one or more OLEDs corresponding to a single pixel, in order to display the required the text or images. The greater the resolution required the greater the number of OLEDs. Multiple OLEDs per pixel are required for colour displays, each OLED per pixel providing complementary colour output so as in combination to achieve a full-colour display. Such displays are often referred to as "paper-like" in that they are both thin and flexible. Clearly, the OLEDs used in this way must emit in the visible spectrum.

Use of organic photo detectors is known in devices such as, for example, photocopiers and laser printers. In such arrangements the organic photo-detector is applied to a rigid surface in the form of a drum formed typically of metal (for example aluminium). A layer over the photo-detector, having low electrical conductivity in the dark, is given a static electrical charge by means of a corona wire. By allowing light – typically in the blue region of the spectrum – to fall in a predetermined pattern onto the photo-detector layer, the electrical charge within the illuminated areas is discharged leaving the charge only on the unilluminated areas. When toner is subsequently applied to the drum, it attaches only to the charged areas, from which it is conveyed to the printing paper. One photo-detecting compound used for photocopier drums is Titanyl Pthalocyanine (TioPC).

US Patent 4,111,850 describes a carbazole based organic photoconductor fabricated specifically on a flexible substrate. However this is designed to detect in the UV spectrum, and although it describes dopants to extend the sensitivity into the visible, these would be unsuitable for detection of red or near infra-red (NIR).

US Patent US 4,167,331 discloses methods of analysing signals from pulse oximeters and other sensors in which light of two different wavelengths is passed through or reflected from a member of the body so as to be modulated by pulsatile blood flow therein. The amplitudes of the alternating current components of the logarithms of the respective light modulations are compared by taking their molecular extinction coefficients into

account so as to yield the degree of oxygen saturation. By adding a third wavelength of light, the percentage of other absorbers in the blood stream such as a dye or carboxyhemoglobin can be measured. Fixed absorbers reduce the amount of light that passes through or is reflected from the body member by a constant amount and so have no effect on the amplitudes of the alternating current components that are used in making the measurements.

US Patent 5,685,299 discloses a further technique for analysing the signals output by similar sensors.

US Patent 6,555,958 describes a method of utilising phosphor to down-convert ultra-violet emissions from LEDs to the blue/green emissions. US Patent 5,874,803 describes use of a filter/phosphor stack to down-convert from blue wavelengths emitted by OLEDs to red/green wavelengths. In both cases down-conversion is to the visible spectrum.

SUMMARY OF THE INVENTION

The present invention provides flexible medical light sources and associated diagnostic devices directed to monitoring blood characteristics (e.g. levels of CO, oxygen, or bilirubin) and photo-therapeutic devices for treatment of ailments such as psoriasis and some forms of cancer. The invention is intended for use both on the human and animal body.

According to a first aspect of the present invention there is provided a medical light source comprising one or more flexible light emitting diodes formed upon a flexible substrate.

Advantageously, a closer and more stable fit can be provided to the patient's body.

In a preferred embodiment, the flexible light emitting source comprises an organic light emitting diode. However other flexible light emitting sources may be employed including, for example, those employing amorphous silicon structures.

In a further preferred embodiment, the flexible light emitting diode emits light at a wavelength suitable for diagnosis or therapy of a medical condition of the human or animal body.

In some preferred embodiments, the flexible light emitting diode emits light in the red to infra-red region of the spectrum.

In a further referred embodiment, the flexible light emitting diode emits light in the near infra-red region of the spectrum.

In some further preferred embodiments, the flexible light emitting diode emits light in a non-visible region of the spectrum. Such regions include the ultra-violet and infra-red.

In a further preferred embodiment, the light source comprises a plurality of flexible light emitting diodes arranged to emit light at mutually distinct wavelengths.

Preferably, at least two of the plurality of flexible light emitting diodes are substantially evenly distributed across an area formed by the sum of their respective areas.

In a further preferred embodiment, the light source comprises a photo-detector arranged, in operation, to detect light emitted from the one or more flexible light emitting diodes.

The light source may also comprise a strap comprising attachment means for attachment of the medical light source around or to a patient's body.

In a preferred embodiment, the flexible substrate forms the strap.

In some preferred embodiments, the attachment means is one of hook-and-loop means, barb-and-slot means, and self-adhesive means.

According to a further aspect of the present invention there is provided a medical sensor comprising two or more medical light sources according to the first aspect and at least one light detector arranged, in operation, to detect light emitted by one or more of the medical light sources.

In some preferred embodiments, the two or more medical light sources are arranged to emit light on a time-interleaved basis.

The medical light sources may be arranged, in operation, to emit light at wavelengths suitable for diagnosis of levels of at least one of oxygen, carbon monoxide, and bilirubin in a human or animal body.

According to a further aspect of the present invention there is provided an organic light emitting diode arrangement comprising an organic light emitting diode arranged to emit light in the blue region of the spectrum and a wavelength-converting layer arranged to convert blue emissions from the organic light emitting diode to emissions in the infra-red region of the spectrum.

In a preferred embodiment, the wavelength-converting layer comprises a phosphor based compound.

In a further preferred embodiment, the wavelength-converting layer comprises an infra-red edge filter.

The invention is also directed to methods by which the described apparatus operates and including method steps for carrying out every function of the apparatus.

The preferred features may be combined as appropriate, as would be apparent to a skilled person, and may be combined with any of the aspects of the invention. Other advantages of the invention, beyond the examples indicated above, will also be apparent to the person skilled in the art.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to show how the invention may be carried into effect, embodiments of the invention are now described below by way of example only and with reference to the accompanying figures in which:

Figure 1(a) shows a schematic diagram of an example of a sensor according to the prior art;

Figure 1(b) shows a schematic diagram of an example of a sensor in accordance to the present invention;

Figure 2 shows a schematic diagram of the structure of a first example of an organic light emitting diode in accordance with the present invention;

Figure 3 shows a schematic diagram of the structure of a second example of an organic light emitting diode in accordance with the present invention;

Figure 4 shows a schematic diagram of the structure of a third example of an organic light emitting diode in accordance with the present invention;

Figure 5 shows a schematic diagram of the structure of an example of a photo-detector in accordance with the present invention;

Figures 6(a) and 6(b) show schematic diagrams of a first sensor arrangement in accordance with the present invention;

Figure 7 shows a schematic diagram of a sensor according to the present invention in operation;

Figures 8 show s a schematic diagram of a second sensor arrangement in accordance with the present invention;

Figure 9 shows an example of a therapeutic light source in accordance with the present invention;

Figure 10 shows a schematic diagram of a therapeutic light source according to the present invention in operation.

Figures 11(a)-11(e) show schematic diagrams of flexible light source layouts in accordance with the present invention;

DETAILED DESCRIPTION OF THE INVENTION

The present inventors have identified that the use of flexible LEDs (for example organic LEDs or polymer based light sources, formed upon flexible substrates) as medical light sources offers many advantages over known light sources for diagnostic and therapeutic purposes.

Referring to Figure 2, a first embodiment of a flexible organic light emitting diode is formed upon a plastic substrate 10, which may be approximately 50 mm long and 13 mm wide. ORGACON ™ flexible substrate (AGFA) may be used. ORGACON is a commercially available PET (Poly Ethylene Terephthalate) film 101 coated with a conductive polymer (PEDOT /PSS– Polyethylene-Dioxythiophene in Polystyrenesulphonic acid) 102. Several varieties of ORGACON are available, of which a preferred variety provides a substrate which is 125 microns thick and has sheet resistance of 350 ohms/square. The OLED is formed upon the substrate by forming successive layers as follows.

Further layers are then evaporated onto the flexible substrate to form a red-emitting OLED:

- a 60 nm layer 13 of NPD (N,N'-diphenyl- N,N'-bis(1-napthylphenyl)-1,1'-biphenyl-4,4'-diamine);
- a 30 nm layer 14 of AlQ (Aluminium 8-hydroxyquinoline) coevaporated with DCM2 (4-Dicyanomethylene-2-methyl-6-[2-(2,3,6,7-tetrahydro-1H,5H-benzo[i,j]-quinolozin-8-yl)-vinyl]-4H-pyran) laser dye at 10% concentration;

- a 30nm 15 layer of AlQ
- a 0.6 nm layer 16 of Lithium Fluoride (LiF); and
- a 150 nm layer 17 of Aluminium to act as cathode.

The resulting red-emitting OLED emits light at approximately 616 nm, corresponding to the emission peak expected from DCM2 laser dye.

Whilst the present specific embodiment uses a substrate of PEDOT and PET, it will be apparent to the person skilled in theart that other flexible substrates could be used including, for example, Indium Tin Oxide (ITO) coated PET from Sheldahl with sheet resistance of 60 ohms/square and PET thickness 150 microns.

In the first embodiment of a near infra-red (NIR) emitting OLED shown in Figure 3, Ytterbium Chloride is mixed with hydroxyquinoline to form a powder (known as YbQ) which was washed, dried and sublimed. An OLED is then constructed with the following layering structure:

- a 68 nm layer 23 of NPD;
- a 38 nm layer 25 of YbQ;
- a 0.6 nm layer 16 of LiF; and
- a 150 nm layer 17 of Aluminium to act as cathode.

The resulting device emits light at the main Ytterbium transition line of 980 nm.

Referring now to Figure 4, a second, preferred, embodiment of a NIR-emitting OLED comprises a blue-emitting OLED constructed using the following layering structure:

- a 68 nm layer 23 of NPD;
- a 10 nm layer 34 of Bathocuproine (2,9-dimethyl- 4,7,-diphenyl-1,10-phenanthroline);
- a 38 nm layer 35 of AlQ;
- a 0.6 nm layer 16 of LiF; and
- a 150 nm layer of 17 Aluminium.

In order to provide a NIR-emitting OLED, a layer 38 of Phosphor Technologies PTIR1070, held in a binder of Norland 65 optical adhesive, is also applied onto the light-emitting face of the flexible substrate. The phosphor layer acts to convert the blue light emitted by the OLED into infra red light at 885 nm. An infra-red edge filter 39, arranged to cut out unwanted visible wavelengths, is then bonded on top of the phosphor layer.

Whilst the above embodiment uses a blue-emitting OLED, a wide variety of blue emitters available. Some are polymers rather than OLEDs, and do not have to be vacuum deposited: they can simply be spun or coated onto the substrate surface. One particular such device structure is:

- anode (e.g. ITO)
- polymer (e.g. 500 nm thick layer)
- cathode (e.g. 100 nm Calcium or Magnesium)

where the polymer layer may be one of:

- PFO Poly(9,9 – dioctylfluoren-2,7,diyl), emitting at 436 nm, or
- Poly-TPD Poly (N,N'-bis(4-butylphenyl)- N,N'-bis(phenyl) benzidine) emitting at 420 nm

Emission around 450 nm is preferred for blue emitter, since this is where phosphor is most sensitive to blue light.

In this as in other cases however, it will be apparent that it is not necessary that the emitter emit exclusively at this specific wavelength, but rather that it is sufficient that it emit sufficiently at a wavelength which is absorbed by the phosphor (i.e. the wavelength converting) layer. In that regard, another suitable source of emissions is in fact a nominally "green" emitting OLED. Such an emitter may be comprise:

- a 68 nm layer of NPD
- a 38 nmm layer of AlQ
- a 0.6 nm layer of LiF
- a 150 nm layer of Al

The resulting OLED emits at around 530 nm ,but with broad wavelength emission. The reason this works is that the phosphor has a broad absorption region, which overlaps sufficiently with the emission spectrum of the nominally "green" OLED.

The light-emitting part of the sensor may not be air-stable, and should typically therefore be encapsulated (for example for use in oximeters and other therapeutic apparatus). This is also important for protecting the skin from the substances used to construct the light sources and photo-conducting layers. A proprietary method of encapsulation can be used for this purpose. One such method is to apply one micron of parylene (poly-para-xylylene) over the whole device, followed by 150 nm of Aluminium over the face upon which the light sources and photo-conductor have been constructed. A third layer, of parylene, at one micron thick is added over the whole device. Other methods of encapsulation may also be used as would be apparent to the skilled person in the art.

To complement the flexible light source, a flexible photo-detector may be provided by forming a photo-detector upon a flexible substrate in a fashion similar to that for creating the flexible OLED. In the applications proposed below however, and unlike their conventional use in devices such as photocopiers and laser printers, the photo-detector is arranged to detect light in the near infra-red (NIR) to red region of the spectrum.

Referring now to Figure 5, a suitable flexible photo-detector comprises a first layer 41 formed from an organic photo-conductor made, in this embodiment, from a solution of Poly Vinyl Carbazole (PVK) in Dichlorobenzene (DCB) at a 10% concentration. Into this solution is mixed a finely ground sample of Titanyl Phthalocyanine (TioPC) in the ratio 3:1 (PVK:TioPC). The resulting mixture is then spun onto the plastic substrate at 2000 rpm for 30 seconds to give a layer in the order of 3-5µm thick. A 100 nm layer 42 of gold acts as cathode.

Preferably the photo-detector is formed on the substrate before formation of the OLEDs as described above.

Referring now to Figures 1(b), 6(a-b), and 7, a medical sensor, for example a pulse oximeter 50, may be constructed making use of such flexible OLEDs and photo-detectors. In particular, the pulse oximeter may comprise a flexible carrier strip 51 to which are attached a pair of OLEDs emitting at different wavelengths. In particular a first OLED 53 emits light in the red part of the spectrum, whilst a second OLED 54 emits in the infra-red part of the spectrum. A photo-detector 52 is located on the carrier strip such that, when the oximeter is wrapped around a bodily part 61 (for example finger or toe) to be

monitored, light emitted from each OLED is received by the photo-detector through the bodily part. The photo-detector and OLEDs are powered, controlled, and monitored via electrical connecting wires 55 coupled to a control mechanism 57. Suitable mechanisms are known in the art. Many other drive schemes and analysis functions exist which would be suitable for use in conjunction with this pulse oximeter sensor.

As has been noted above, OLEDs and photo-detectors may be formed upon flexible substrates. It is therefore possible (though not essential) to form both the OLEDs and the photo-detectors on a single substrate which forms the flexible carrier strap. This simplifies manufacture by removing steps associated with attaching separately manufactured light sources and detectors to a separate carrier strap as in known sensors. Clearly in the present arrangement, all necessary electrical connections may also be formed upon the same substrate as part of the same manufacturing process.

Whilst the present embodiment shows only a single detector 52 sensitive to the emission wavelengths of both light sources 53, 54, alternative embodiments clearly include those having multiple detectors, each sensitive to emissions from respective light sources.

The carrier strip 51 may be fixed around the patient by any of a number of attachment means including in particular hook-and-loop means 56a, 56b. Hook-and-loop means is particularly suitable for this arrangement since the flexibility of the OLEDs and photo-detector allow the carrier strip to follow the contours of the bodily part much more closely than do the rigid components of known oximeters. As a result there is much less likelihood of slippage around or off of the patient's digit or limb. The carrier strip itself 51 may be of a stretchable material to facilitate attachment and allow for some variation in patient sizes. The use of hook-and-loop style fastenings (or indeed other re-usable fastening means including "poppers") also facilitates repeated removal and reattachment of the oximeter without loss of fastening strength or functionality.

In a further embodiment, shown in Figure 8, the substrate forming the strap itself may be formed to provide the attachment means. One or more slots 96a may be provided in one end of the strap whilst the other end is narrowed and provided with barbs 96b. In operation, the strap may be passed around the patient and the barbed end slid through one or other of the slits and gently tightened sufficiently to retain the strap around the patient. Clearly, two or more pairs of slots and barbed inserts may be used where appropriate, especially for larger devices.

This form of attachment obviates having to attach additional components to the strap to provide the attachment means. Instead the straps may be simply cut to shape from a sheet or roll during manufacture in a simple, continuous operation.

In another embodiment, a portion of the strap is pre-coated with an adhesive so that, in operation, that portion of the strap may be stuck to the outside face of the strap when placed around a patient. This avoids applying the adhesive directly to the patient.

Although the description above has been directed to a pulse oximeter, the techniques involved may of course be applied to a wider range of devices and applications.

In particular, the number of OLEDs in a given device may be increased to three or more, each emitting at a distinct wavelength so as to provide for different sensors adapted to detect other patient characteristics.

It is possible then to measure the concentration of other components in the blood (for example carbon monoxide or bilirubin) by using a third wavelength light source and solving three simultaneous equations using, for example, the technique described in patent US 4,167,331. Detection of both CO and bilirubin relies on a device which emits at 668 nm. Such a source may be based upon Poly ([9,9 -dihexyl-2,7 - bis(1-cyanovinylene) fluorenylene]-alt-co-[2,5-bis(N,N'-diphenylamino)-1,4-phenylene]) ("Poly-CFD"). This compound is available from HW Sands Ltd as Catalogue number OHA2212. The OLED has the following structure:

- anode (e.g. ITO/PEDOT);
- polymer (Poly-CFD as above) (e.g. 500nm)
- cathode (e.g. calcium/Magnesium) (100 nm)

The resulting OLED emits at approximately 668 nm. By employing such an emitter in conjunction with, for example, two OLEDS as for the pulse oximeters 50 described above, it is possible to provide a detector for carbon monoxide (CO) levels in the bloodstream.

A further embodiment provides a sensor for cardiac output measurement using a well-known technique involving injecting dye into a site. By measuring and comparing the dye concentration upstream and downstream of the injection site, cardiac output or flow may be determined. This is known as Fick's Principle.

Some such dyes include Methylene Blue, which absorbs light at 668 nm. By constructing a sensor comprising two OLEDS as in the pulse oximeter in combination with a third OLED emitting at 668 nm, the concentration of Methylene Blue, and hence cardiac flow, may be determined.

To prevent stray incident light from other sources affecting the photodetector, a suitably light-proof layer may be provided around the back of the light sources and/or detector. The layer may take any suitable form to block incident light from the rear of the OLED and detector: for example as a light-proof layer deposited on the back of the OLED, or as a separate physical member attached to the OLED, or a separate physical member merely loosely wrapped around the OLED while in use. The light-proofing should be sufficient at least to block wavelengths to which the detector is sensitive.

Referring now to Figures 9 and 10, in another embodiment, a flexible light source is provided to illuminate a portion of a body with light of a predetermined wavelength, the chosen wavelength having a therapeutic value. The flexible light source may be in the form of an OLED 106. In such applications the area of the OLED will typically be much larger than that employed in, for example, the pulse oximeter. This is because it will often be appropriate to illuminate a largish portion of the patient's body. However, for highly localised treatment, smaller light sources could of course be employed. Flexible light sources may therefore be readily manufactured in any size to suit different treatments.

Employing a flexible light source has the advantage that, instead of requiring the patient to remain stationary in the vicinity of a large and unwieldy light source, the new device – being lightweight, flexible, and portable – may be rolled or otherwise applied relatively closely over or around a bodily member 111 and can be readily carried around by the patient during treatment.

One particular such application is for UV Phototherapy for skin conditions including, but not limited to, psoriasis. The inventors have noted that Poly[(9,9-dioctylfluoren-2,7-diyl)-alt-co-(2,2'-bipyridin-6,6'-diyl)] (PFO-BD) is a UV OLED emitter (available from HW Sands Ltd catalogue number OPA3191) emits at 369 and 392 nm when cast from solution. It is therefore possible to construct a flexible OLED having the following structure:

- anode (e.g. ITO/PEDOT)
- PFO-BD (e.g. 500 nm)

- cathode (e.g. Calcium or Magnesium 100 nm)

To prevent leakage of UV light in unwanted directions, a light-proof layer may be provided around the back of the light source. The layer may take any suitable form to block emissions to the rear of the OLED: for example as a UV light-proof layer deposited on the back of the OLED, or as a separate physical member attached to the OLED, or a separate physical member merely loosely wrapped around the OLED while in use.

By providing such a flexible light source which may be wrapped relatively closely around only the affected area of the body, and which mitigates stray emissions not required for therapy, the risk of damage to the eyes from stray UV light from the light source may be significantly reduced. By being able to locate the light source substantially uniformly closely around the bodily part, it is also possible to consistently obtain more even coverage to the whole of an affected area than may be possible using conventional UV lamps positioned more remotely over or around the affected area.

Turning now to applications in photodynamic therapy, one dye used is Photofrin which absorbs light at 630 nm. A red-emitting OLED emitting at around 630nm used as illuminator therefore emits at an appropriate wavelength to effect treatment. The DCM-doped OLED described above in connection with the pulse oximeter embodiment is one such OLED which may also be used for photodynamic therapy in conjunction with Photofrin.

Other dyes which may be used in photodynamic therapy include, for example, benzoporphyrin derivatives (BPD) which absorb at 680 nm. In this case a deep red emitter (around 668 nm) is required, such as that described above.

These embodiments can enable greater penetration of light to tumour sites by virtue of their wrap-around design which enables close proximity illumination and light penetration from all angles around the tumour site.

A further benefit of such medical light sources is that OLEDs emit over a relatively narrow spectrum compared to conventional lamps used for therapy. Use of OLEDs as light sources therefore helps mitigate the levels of undesirable light emissions directed to the affected area during treatment. In particular, incidental infra-red emissions may be reduced compared with known light sources. This is beneficial to the patient since excessive infra-red exposure can damage otherwise healthy tissue.

A further feature enabled through use of OLEDs rather than LEDs is that OLEDs offer a substantially 180 degree angle of illumination, compared to the narrower emission angle associated with LEDs. As a result the precise alignment on the patient of devices using OLEDs is less critical and this in itself acts to mitigate the impact of the penumbra effect in the monitoring sensors.

However the penumbra effect may be further mitigated by tailoring the shape of the OLEDs in the sensor so that their areas of emission are substantially interleaved in such a way that, for practical purposes, they effectively emit light over either very closely situated areas or, preferably, substantially co-extensive areas. This can be achieved by any one of many layouts each comprising two or more OLEDs, the OLEDs being selected to emit at one of two or more respective wavelengths. Examples of such layouts are shown in Figures 11(a-e), which illustrate respectively:

- a chequerboard arrangement of two wavelengths employing four OLEDs 81a-84a;
- a spiral arrangement of two wavelengths using two OLEDs 81b-82b;
- an interleaved comb arrangement of two wavelengths using two OLEDs 81c-82c;
- an arrangement of four wavelengths using four OLEDs 81d-84d; and
- an arrangement of two wavelengths employing six OLEDs 81e-86e, three of each wavelength.

Many other configurations are possible as would be apparent to the person skilled in the art. Mitigation of the penumbra effect makes precise alignment of the device on the patient less critical and hence more reliable and less time-consuming.

This flexibility in topography of the OLEDs is further enhanced by being able to form a single wavelength-emitting OLED in multiple, disjoint areas, and coupling together electrically emitters of the same wavelength to allow them to be operated as a single OLED. An example of one such suitable arrangement is shown in Figure 11(a) when OLED 81(a) is coupled to OLED 83(a), OLED 82(a) is coupled to OLED 84(a). Figure 11(e) shows an arrangement of two groups of three coupled OLEDs.

Any range or device value given herein may be extended or altered without losing the effect sought, as will be apparent to the skilled person for an understanding of the teachings herein.

CLAIMS

1. A medical light source comprising one or more flexible light emitting diodes formed upon a flexible substrate.

2. A medical light source according to any preceding claim in which the flexible light emitting source comprises an organic light emitting diode.

3. A medical light source according to any preceding claim in which the flexible light emitting diode emits light at a wavelength suitable for diagnosis or therapy of a medical condition of the human or animal body.

4. A medical light source according to any preceding claim in which the flexible light emitting diode emits light in the red to infra-red region of the spectrum.

5. A medical light source according to any preceding claim in which the flexible light emitting diode emits light in the near infra-red region of the spectrum.

6. A medical light source according to any preceding claim in which the flexible light emitting diode emits light in a non-visible region of the spectrum.

7. A medical light source according to any preceding claim comprising a plurality of flexible light emitting diodes arranged to emit light at mutually distinct wavelengths.

8. A medical light source according to any preceding claim in which at least two of the plurality of flexible light emitting diodes are substantially evenly distributed across an area formed by the sum of their respective areas.

9. A medical light source according to any preceding claim comprising a photo-detector arranged, in operation, to detect light emitted from the one or more flexible light emitting diodes.

10. A medical light source according to any preceding claim comprising a strap comprising attachment means for attachment of the medical light source around or to a patient's body.

11. A medical light source according to claim 8 in which the flexible substrate forms the strap.

12. A medical light source according to any one of claims 10-11 in which the attachment means is one of hook-and-loop means, barb-and-slot means, and self-adhesive means.

13. A medical sensor comprising two or more medical light sources according to any one of claims 1-12 and at least one light detector arranged, in operation, to detect light emitted by one or more of the medical light sources.

14. A medical sensor according to claim 12 in which the two or more medical light sources are arranged to emit light on a time-interleaved basis.

15. A medical sensor according to any one of claims 13-14 in which the medical light sources are arranged, in operation, to emit light at wavelengths suitable for diagnosis of levels of at least one of oxygen, carbon monoxide, and bilirubin in a human or animal body.

16. A medical light source substantially as described in the foregoing description with reference to the accompanying figures.

17. A medical sensor substantially as described in the foregoing description with reference to the accompanying figures.

18. An organic light emitting diode arrangement comprising an organic light emitting diode arranged to emit light in the blue region of the spectrum and a wavelength-converting layer arranged to convert blue emissions from the organic light emitting diode to emissions in the infra-red region of the spectrum.

19. An organic light emitting diode arrangement according to claim 18 in which the wavelength-converting layer comprises a phosphor based compound.

20. An organic light emitting diode arrangement according to any one of claims 18-20 in which the wavelength-converting layer comprises an infra-red edge filter.

21. An organic light emitting diode arrangement substantially as described in the foregoing description with reference to the accompanying figures.

ABSTRACT

Flexible medical light sources and resulting diagnostic devices directed to monitoring blood characteristics (e.g. levels of CO, oxygen, or bilirubin) and photo-therapeutic devices for treatment of ailments such as psoriasis and some forms of cancer. The flexible light source preferably comprises one or more organic light emitting diodes on a flexible substrate. The substrate can also form a integral strap for attachment of the device over or around the patient's body. Optionally, the device comprises a photo-detector arranged to detect and monitor emissions from the sources.

Figure 1(a) **Prior Art**

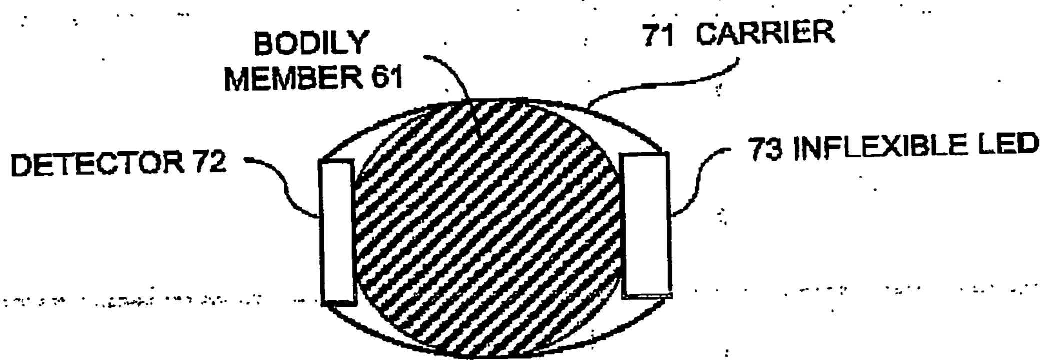


Figure 1(b)

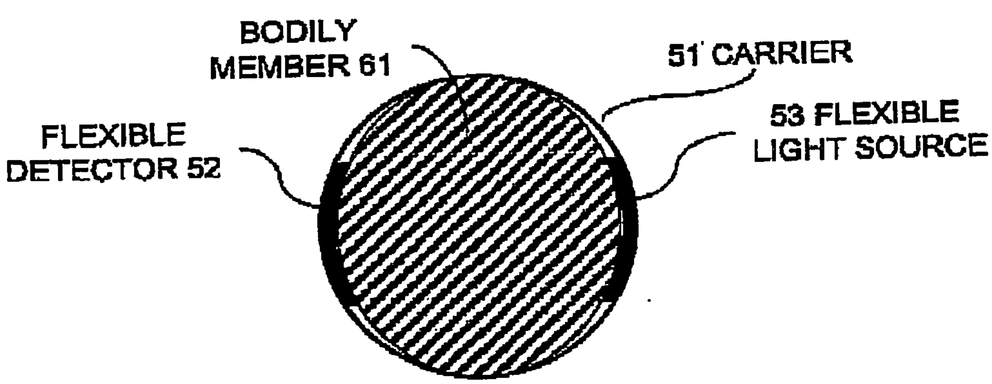


Figure 2

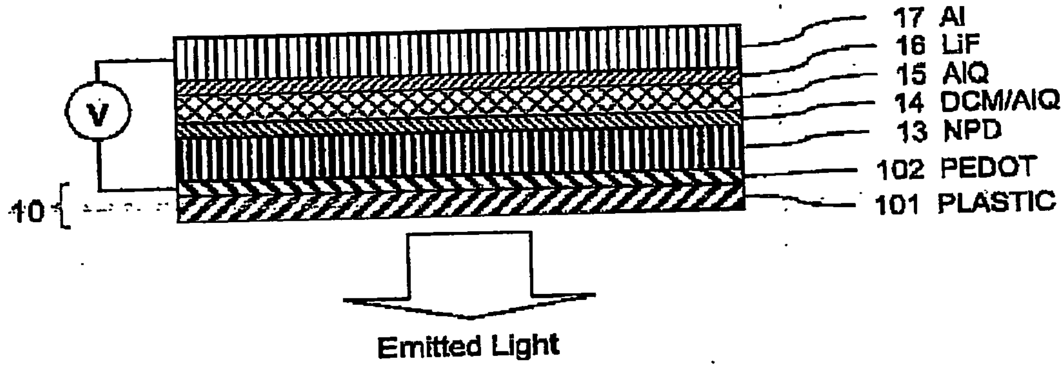


Figure 3

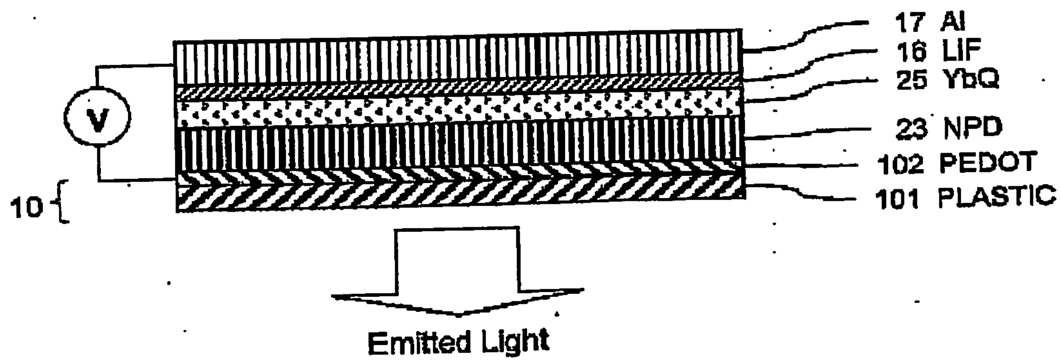


Figure 4

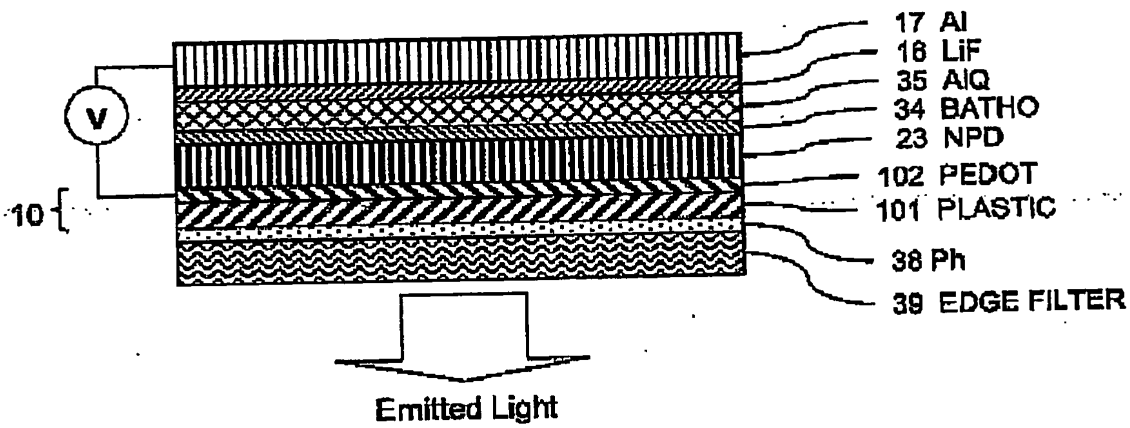


Figure 5

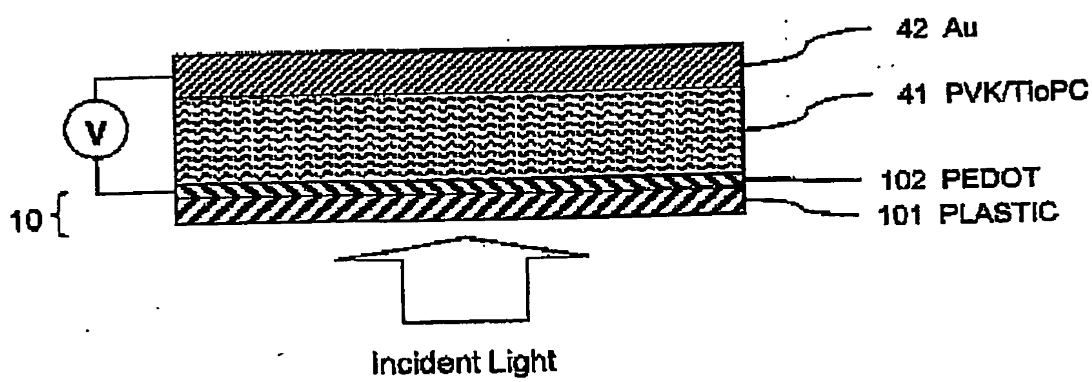


Figure 6(a) **Figure 6(b)**

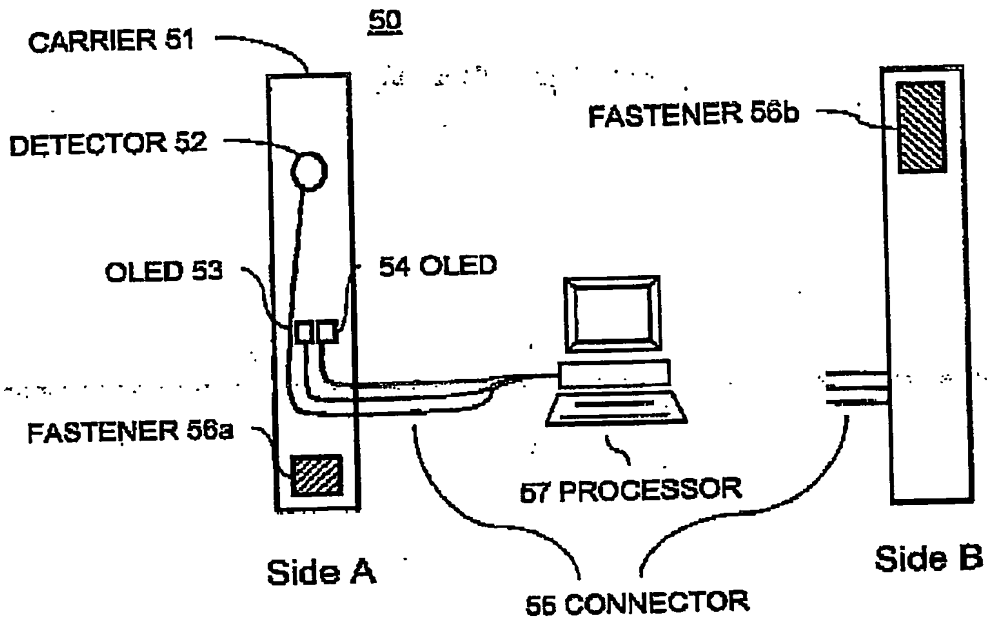


Figure 7

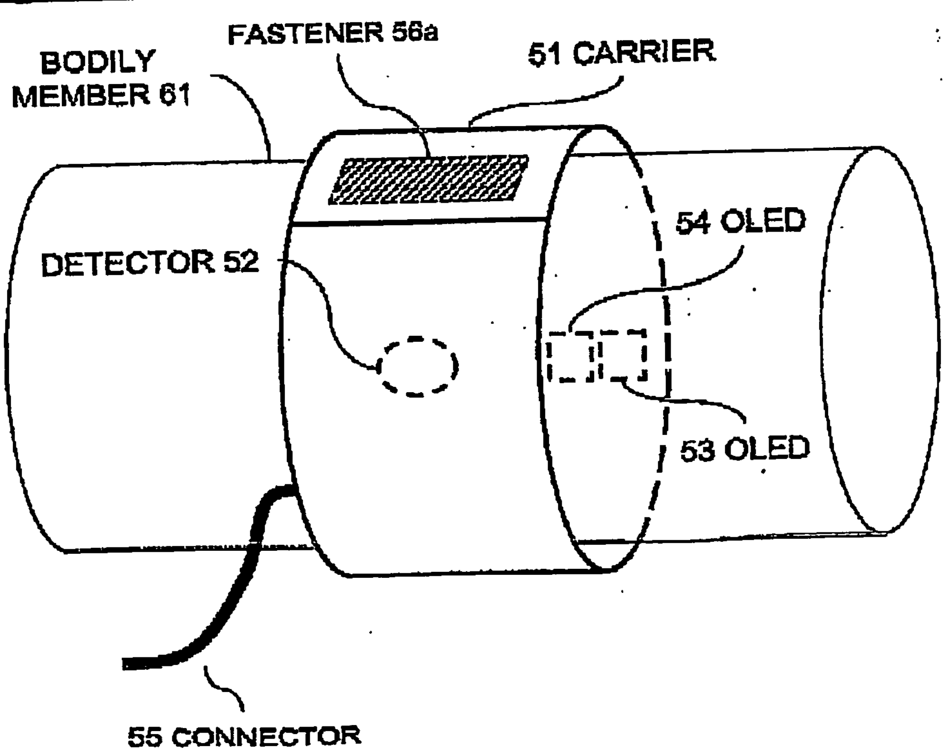


Figure 8

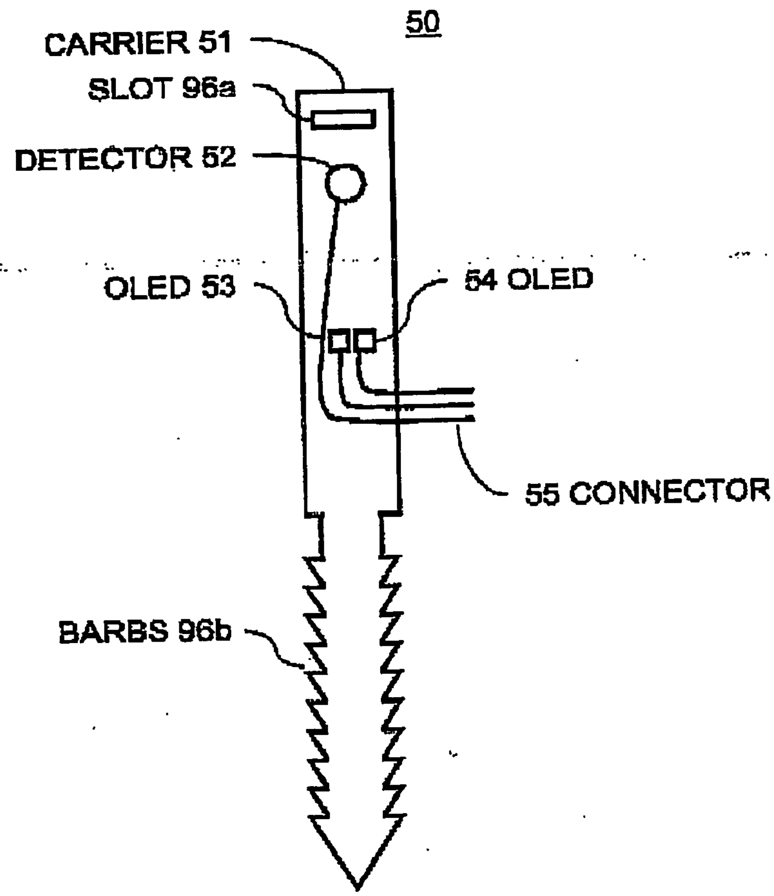

50
CARRIER 51
SLOT 96a
DETECTOR 52
OLED 53
54 OLED
55 CONNECTOR
BARBS 96b

Figure 9

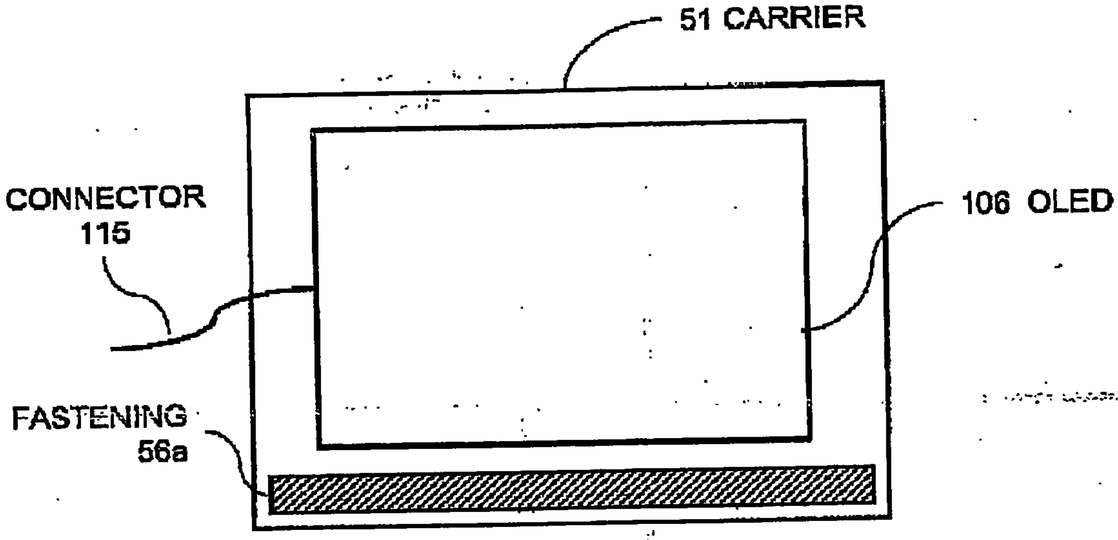


Figure 10

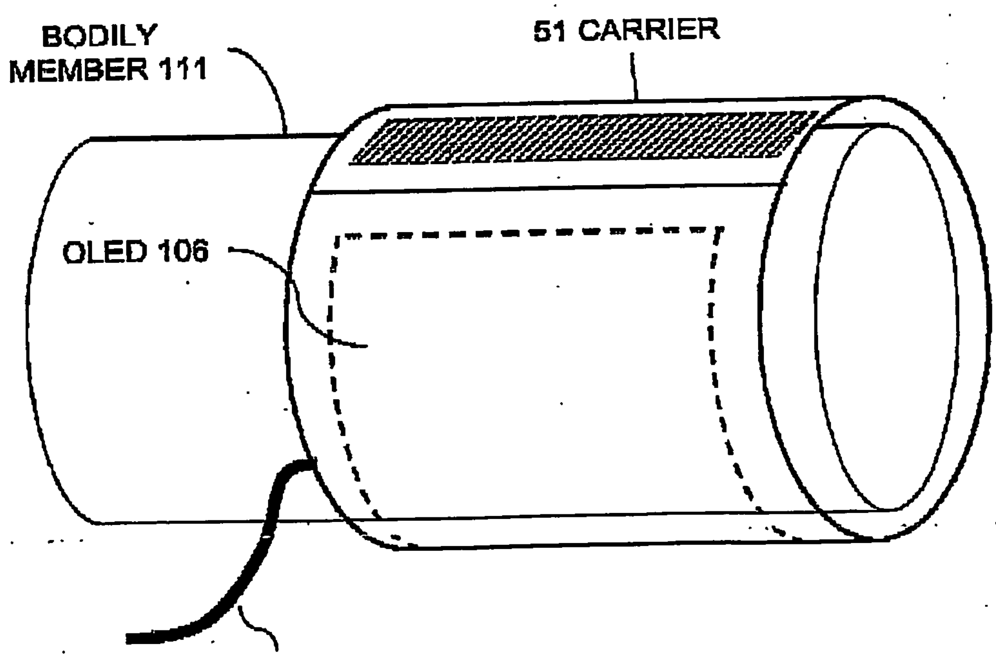


Figure 11(a)

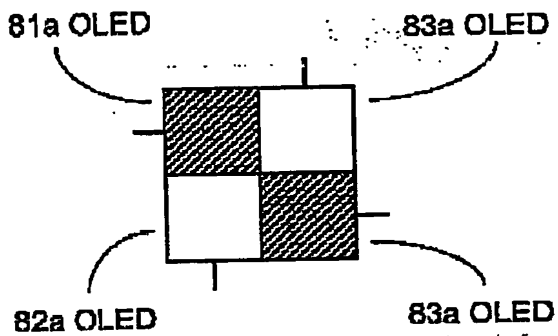


Figure 11(b)

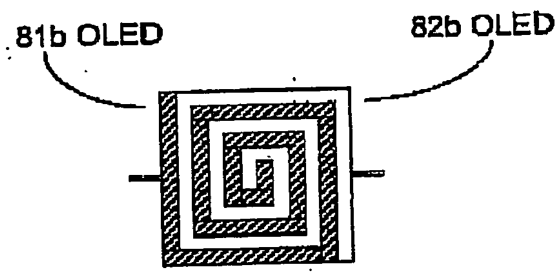


Figure 11(c)

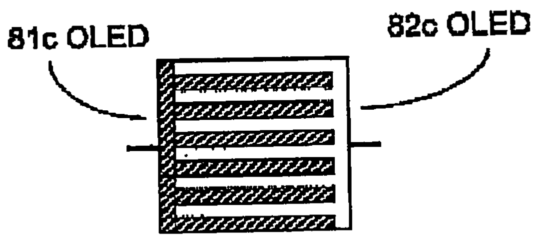


Figure 11(d)

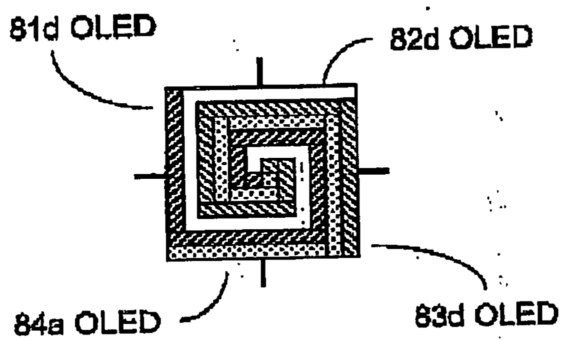
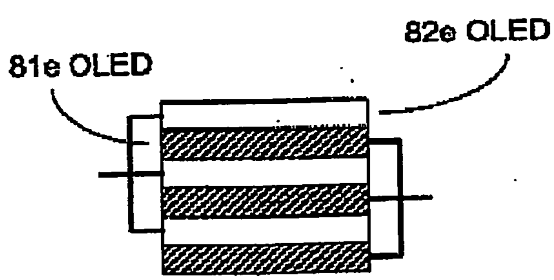


Figure 11(e)



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